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# Study of how Environmental Fluctuations Influence the Coherence of Acoustic Signals


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# Study of how Environmental Fluctuations Influence the Coherence of Acoustic Signals

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## Abstract

This project supported the graduate studies and research of Claire Debever in the area of matched-field processing. The aim is to combine adaptive and coherent broadband methods to ultimately develop a robust matched-field processing technique well suited for practical applications in challenging environments.

## Research summary

Matched-field processing (MFP) is based on the comparison between the recorded acoustic data and the synthetic one issued from a source at a hypothetical position, an environmental model of the waveguide and a propagation code. When the source signal is weak, and/or propagates in a noisy waveguide, using an array of sensors to coherently add the signal received at each element is essential to distinguish the signal from the noise. Adaptive formulations are extensively used to lower the level of the noise and suppress interferers. Unfortunately, they are not only very sensitive to mismatch, but also require the obtention of a full rank cross-spectral density matrix and received sound levels to exceed a threshold signal-to-noise ratio. Coherent broadband MFP offers a way to increase the signal-to-noise ratio by adding an extra-processing gain. However, the sensitivity to mismatch and the difficulty to accumulate enough snapshots to create a well-conditioned cross-spectral density matrix also increases. The white noise constraint method, typically used for narrow-band processing, is now applied in a broadband context to enhance the robustness to environmental mismatch and snapshot deficiency.

The coherent broadband algorithm developed by Michalopoulou and Porter (IEEE J. Ocean. Eng. **21**, 384-392, 1996) is combined with the adaptive white noise constraint method on data from the Hudson Canyon data set experiment. An acoustic source was towed in shallow water (73 m) at 36 m depth up to 4.5 km from the 24-elements receiver array. Multitones were sent between 50 and 600 Hz. Fig. 1 and 2 show a comparison of the localization performances of the white noise constraint algorithm using four frequencies incoherently versus coherently. The algorithm is not only robust to mismatch between the experimental and modeled fields since the source is successfully localized,

but also discriminating, as suggested by the absence of any sidelobes up to 40 dB under the peak value. In fact the noise level is 146 dB lower than the signal level suggesting the presence of a bias in dynamic range.

This bias in dynamic range can be attributed to the amount of diagonal loading - independent of the look direction – applied to the cross-spectral density matrix to render it invertible. A theoretical description of the bias versus the ratio of static loading and noise eigenvalues is developed. The results are consistent with the experimental dynamic range obtained.

The source tracking performance of the coherent broadband white noise constraint processor is also evaluated in presence of a slight sound speed mismatch. The localization in range and depth of the coherent and incoherent minimum variance (Fig. 3) and white noise constraint (Fig. 4) matched-field processors is compared. The latter algorithm is shown to be more robust to environmental mismatch and produce low sidelobes when combined to a coherent broadband algorithm like the one developed by Michalopoulou and Porter.

The typical way to increase the signal-to-noise ratio at the output of the array is to increase the number of receiver elements. But larger arrays are less practical than shorter ones. Using multiple short arrays recording the source signal from different locations in the waveguide represents an interesting compromise. This time, two type of coherence can be studied: the coherence across frequency, as done in the first section, but also the coherent contributions between receivers from different sub-arrays. A coherent inter-array processing of the data is expected to give a more accurate source localization result, providing that the distance between individual arrays is small enough that the inter-array signal remains coherent.

The SWellEx-96 experiment is chosen to test the performance of all the combinations of coherent and incoherent processors across frequencies or/and arrays. An acoustic source sending multitones between 110 and 400 Hz was towed 9 m deep in shallow water (200 m) up to 3 km away from two 27-element horizontal line arrays.

Since the point of the processor is to coherently treat the signal between individual arrays, one of the first steps of the method is to assess how much coherence, if any, we can actually expect from signals received at such distant locations. Indeed the distance between the arrays is 200 to 800 times larger than the signal wavelength at such frequencies. A comparison between the dynamic ranges obtained from ambiguity surfaces for every combination of incoherent or coherent processing between arrays and frequencies (Fig. 5) shows that the method indeed yields a coherent gain of about 0.9 dB when using inter-array contributions coherently, and an additional 3.3 dB when processing frequencies coherently.

The tracking capability of the algorithm is then evaluated (Fig. 6). The source is tracked in the region broadside from the arrays, but not when endfire from one or the other.

Exploiting the coherence of signals across frequencies or arrays is important to increase the signal-to-noise level at the output of the array. But because it also enhances the processor’s sensitivity to mismatch and snapshot deficiency, it is essential to combine it with a robust adaptive matched-field processing method. The white noise constraint

method was shown to be a robust, discriminating, high-resolution processor well suited for practical applications.

## Publication

Claire Debever and W. A. Kuperman. ‘Robust matched-field processing using a coherent broadband white noise constraint processor”, J. Acoust. Soc. Am. **122** (4), October 2007 [published].

## Conferences

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## Figures

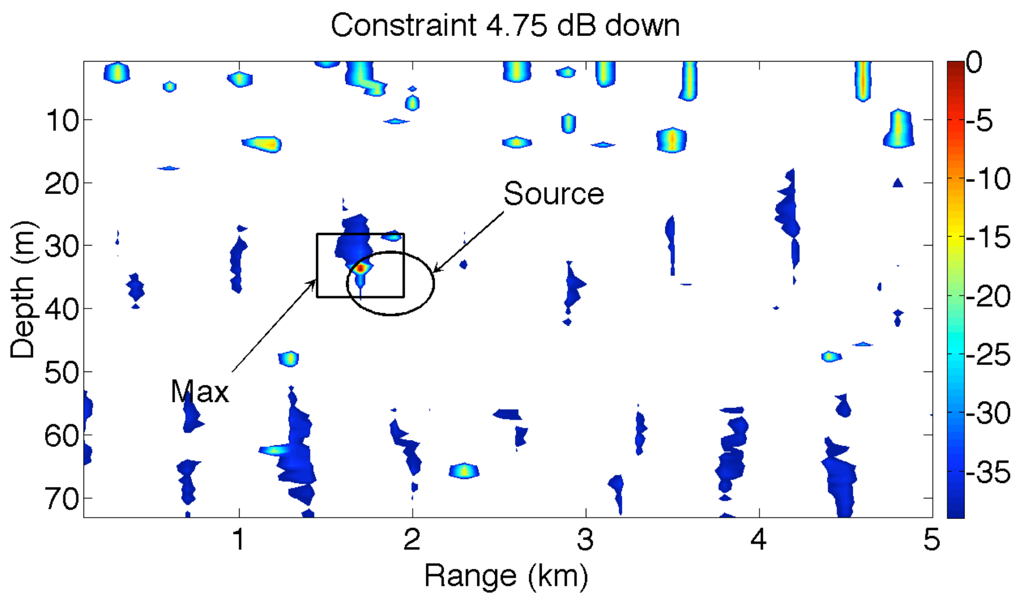



Fig. 1. White noise constraint MFP obtained by an incoherent decibel average of four frequencies ambiguity surfaces (50, 175, 375, and 425 Hz). The source is localized and the first sidelobes appear 10 dB down from the main peak. The white color corresponds to a level beyond the dynamic range.

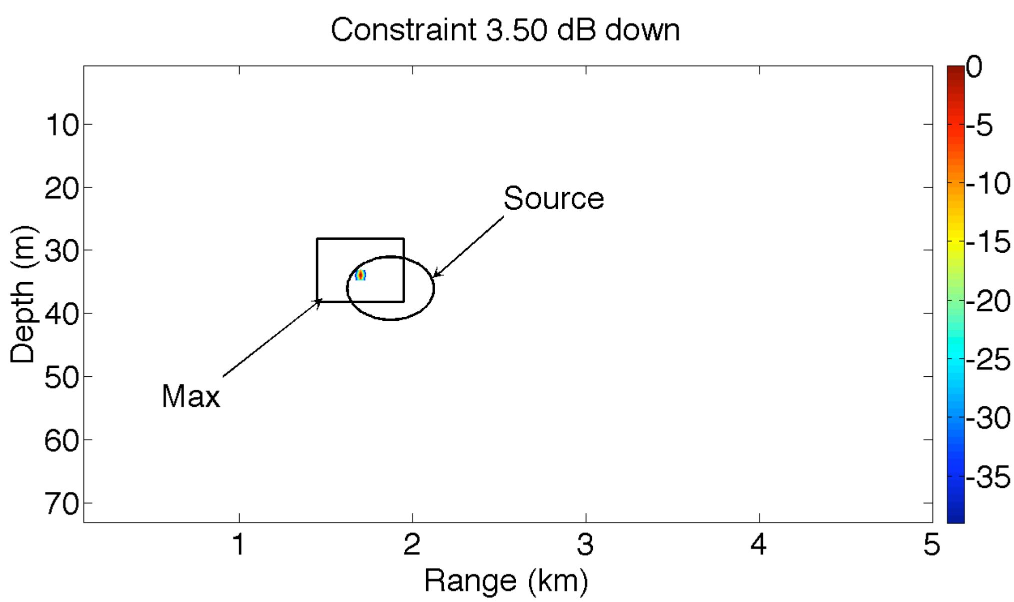
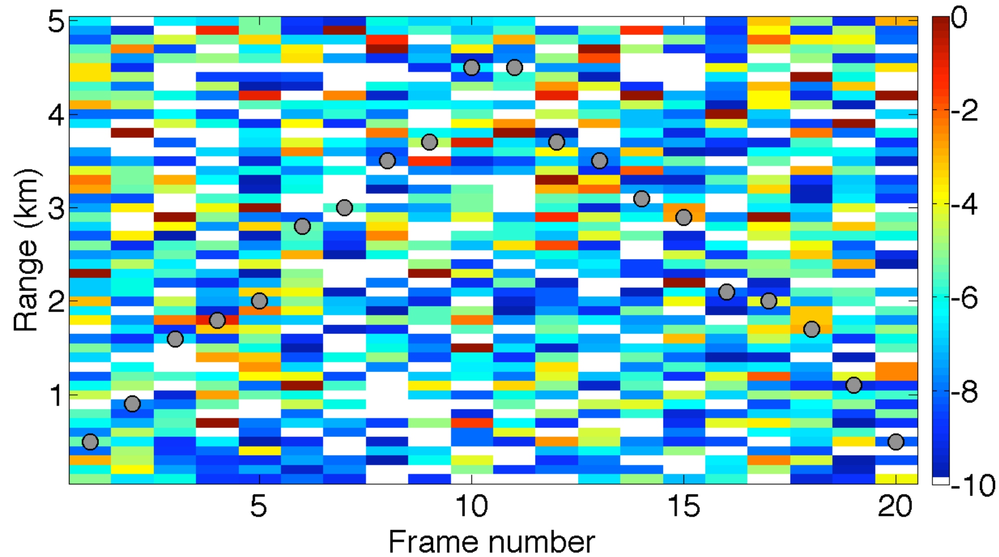
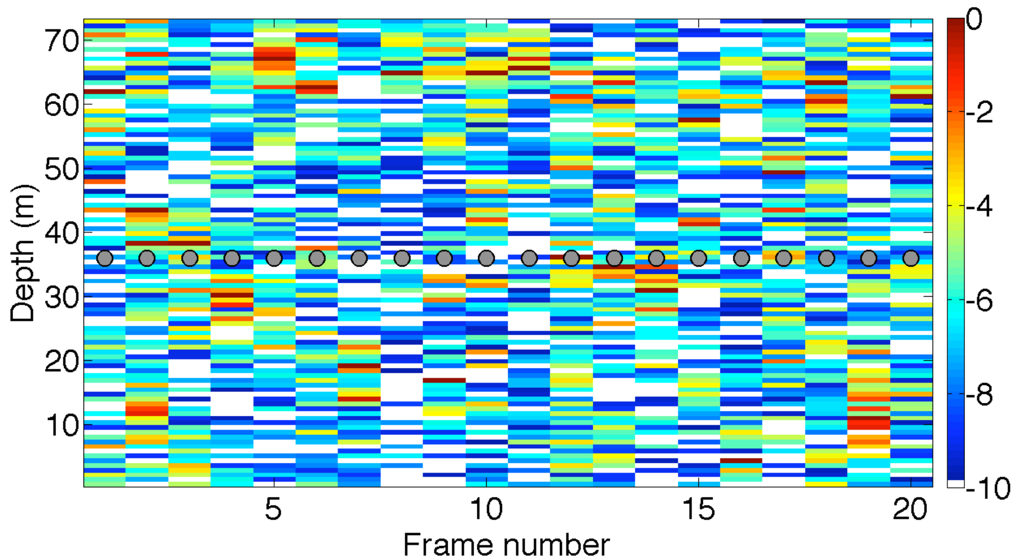



Fig. 2. Output from the Michalopoulou/Porter coherent broadband white noise constraint MFP using four frequencies (50, 175, 375, and 425 Hz). The main peak is at the true source position, and stands 146 dB above the noise. The white color corresponds to a level beyond the dynamic range. The dynamic range is set to 40 dB for comparison purposes with Fig 1.

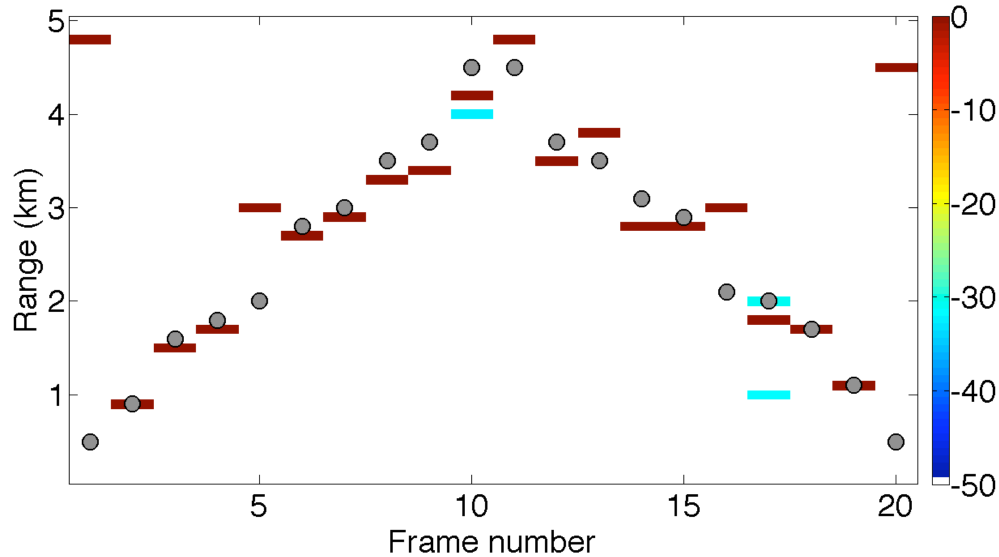



(a)

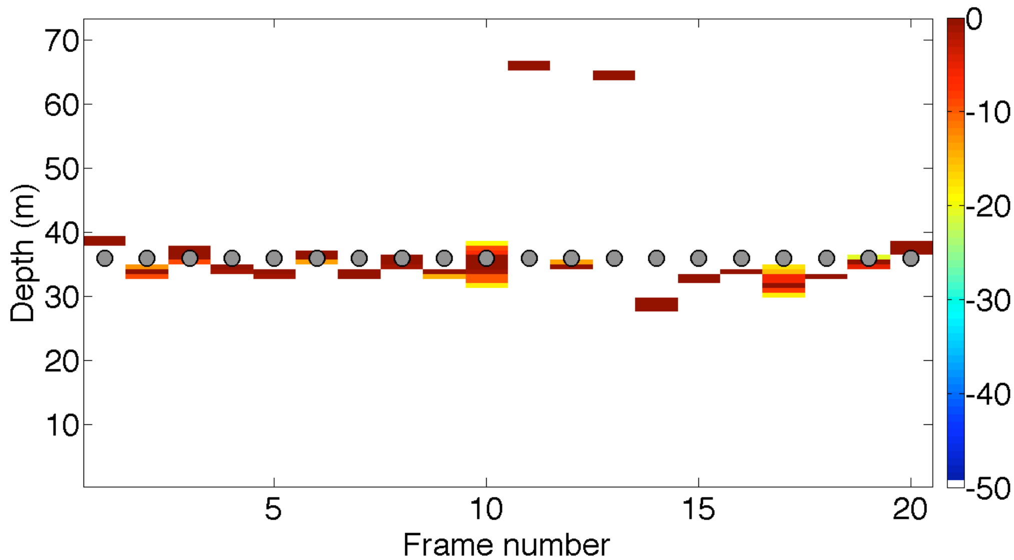



(b)

Fig. 3. Source track obtained using the coherent Michalopoulou/Porter minimum variance algorithm in the presence of mismatch. The black circles indicate the true source positions and the white color corresponds to a level beyond the dynamic range. (a) Range track at source depth of 36 m and (b) depth track along the estimated range track.




(a)




(b)

Fig. 4. Source track obtained using the coherent Michalopoulou/Porter white noise constraint algorithm in the presence of mismatch. The black circles indicate the true source positions and the white color corresponds to a level beyond the dynamic range. (a) Range track at source depth of 36 m and (b) depth track along the estimated range track.

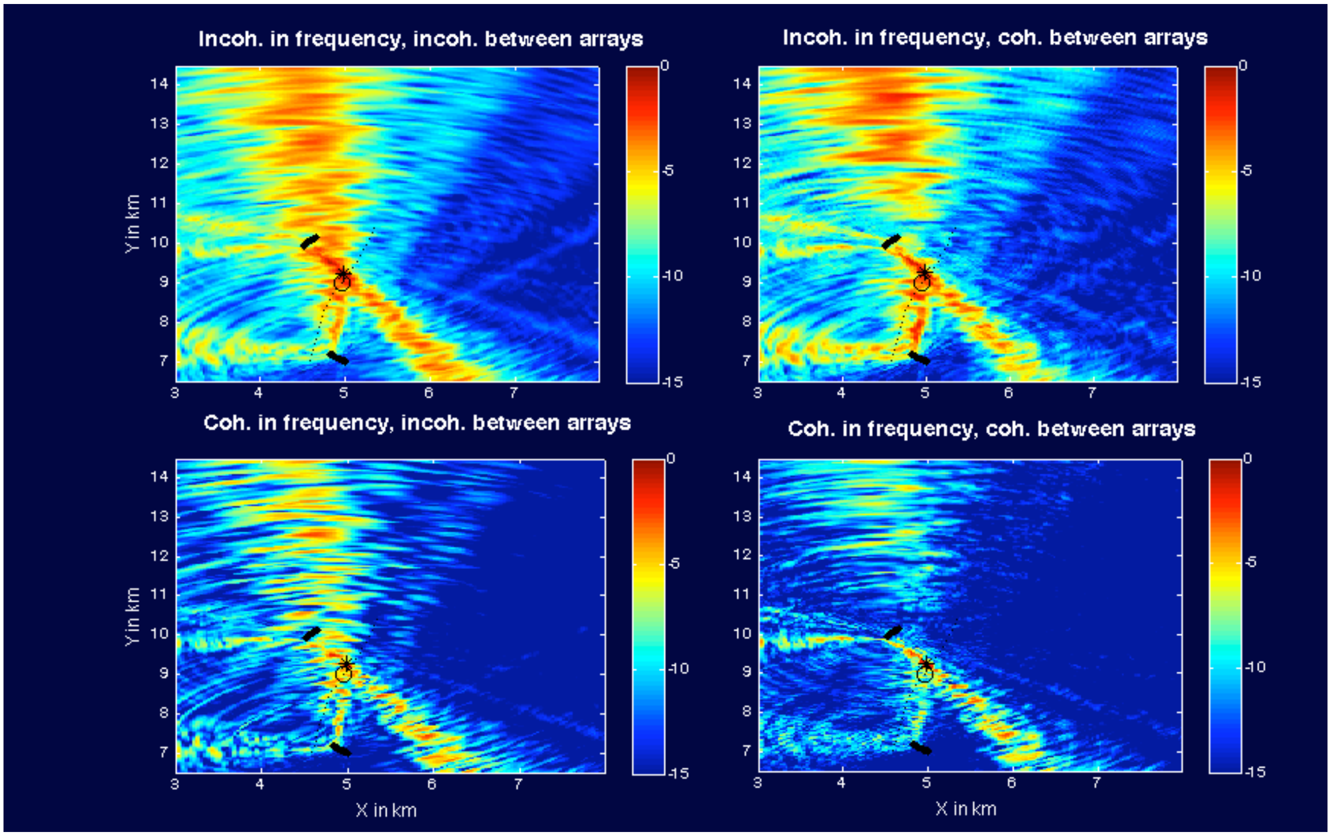



Fig. 5. Example of source localization. The arrays are represented by the two black lines, the true source position by the black circle, and the found source position by the black star.

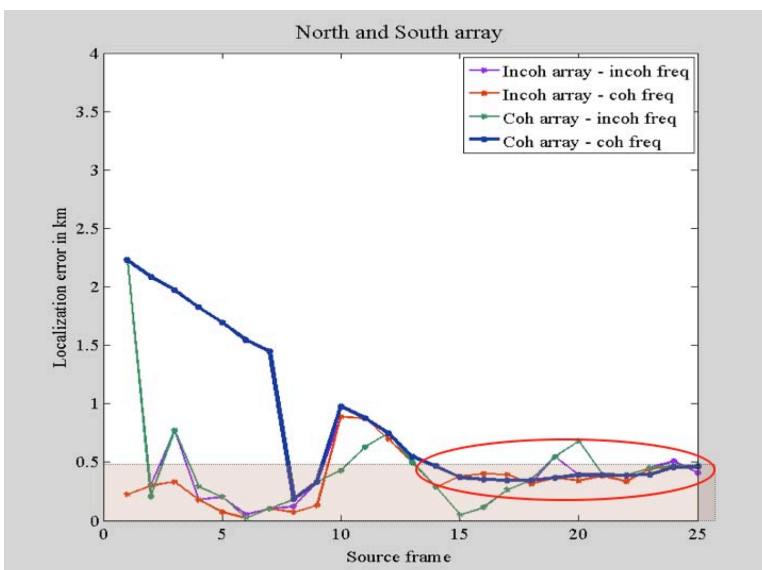



Fig. 6. Error in the source position for each processor.